

WHAT IS CLAIMED IS:

1 1. A microfluidic system for liquid chromatography, the system
2 comprising:
3 a substrate;
4 an electrochemical pump system on the substrate, the electrochemical pump
5 system comprising a plurality of electrolysis pumps and having at least one outlet; each of the
6 electrolysis pumps comprising:
7 a chamber;
8 a plurality of electrodes, the electrodes being coupled to an electrical
9 source;
10 a fluid inside the chamber, and the fluid being contacted with the
11 electrodes; and
12 an inlet and an outlet;
13 an separation column on the substrate having an inlet and an outlet, an micro
14 channel, a solid stationary phase material packed inside the micro channel, the inlet of the
15 separation column being coupled to the at least one outlet of the electrochemical pump
16 system; and
17 wherein the electrochemical pump system and the separation column are
18 configured such that the electrochemical pump system provides an elution for a separation
19 process inside the separation column.

1 2. The system of claim 1 wherein the plurality of electrolysis pumps are
2 configured in parallel.

1 3. The system of claim 1 wherein the plurality of electrolysis pumps are
2 configured in serial.

1 4. The system of claim 1 wherein the plurality of electrolysis pumps are
2 configured in parallel and serial.

1 5. The system of claim 1 wherein the elution provided by the
2 electrochemical pump system is isocratic elution.

1 6. The system of claim 1 wherein the elution provided by the
2 electrochemical pump system is gradient elution.

1 7. The system of claim 1 wherein one of the electrolysis pumps is a
2 sample injector and wherein the separation column is configured to perform a separation of
3 one or more components of the sample dispensed from the sample injector as the rest of
4 electrolysis pumps provide the elution for the separation column.

1 8. The system of claim 1 further comprising:
2 a sample source, the sample source comprising a sample;
3 an sample injector on the same substrate coupled between the electrochemical
4 pump and the separation column, the sample injector being coupled to the sample source; and
5 wherein the separation column is configured to perform a separation of one or
6 more components of the sample dispensed from the sample injector as the electrochemical
7 pump system provides the elution for the separation column.

1 9. The system of claim 1 wherein the electrical source is selected from a
2 group consisting of a voltage source, a current source, and a voltage/current source.

1 10. The system of claim 1 wherein the electrolysis pump is adapted to
2 maintain a pressure on the fluid in the chamber while the electrodes are biased using the
3 electrical source.

1 11. The system of claim 10 wherein the pressure is greater than 1000 psia.

1 12. The system of claim 10 wherein the pressure is less than 1000 psia.

1 13. The system of claim 10 wherein the pressure is less than 100 psia.

1 14. The system of claim 1 wherein the chamber comprises about 1 micro
2 liter of fluid.

1 15. The system of claim 1 wherein the chamber comprises greater than
2 about 1 micrometer of fluid.

1 16. The system of claim 1 wherein the chamber comprises less than about
2 1 micrometer of fluid.

1 17. The system of claim 1 wherein the electrochemical pump system is
2 characterized to provide a flow rate of about 1 nanoliter per minute to about 1 micro liter per
3 minute through the separation column.

1 18. The system of claim 1 wherein the electrochemical pump system is
2 characterized to provide a flow rate of less than about 1 nanoliter per minute through the
3 separation column.

1 19. The system of claim 1 wherein the electrochemical pump system is
2 characterized to provide a flow rate of greater than about 1 micro liter per minute through the
3 separation column.

1 20. The system of claim 1 wherein the chamber and the separation column
2 are made of materials including Parylene.

1 21. The system of claim 1 wherein the chamber and the separation column
2 are made of materials selected from a group consisting of SU-8, silicone, silicon, silicon
3 oxide, glass, Teflon, PEEK, and other polymer materials.

1 22. The system of claim 1 wherein the electrodes are made of at least a
2 material selected from a group consisting of carbon, platinum, gold, aluminum, titanium,
3 chromium, and other noble metals.

1 23. The system of claim 1 wherein the fluid being an electrolyte that is
2 selected from a group consisting of organic liquid, inorganic liquid, or a combination of
3 inorganic liquid and organic liquid.

1 24. The system of claim 23 wherein the organic liquid is selected from a
2 group consisting of acetonitrile, methanol, ethanol, tetrahydrofuran, isopropanol, and toluene.

1 25. The system of claim 1 wherein the electrolysis pump further
2 comprising a plurality of chambers configured in series and containing same or different fluid
3 inside each chamber.

1 26. The system of claim 1 further comprising a mixer on the same
2 substrate coupled between the electrochemical pump system and the separation column, the
3 mixer is configured such that different components of the elution provided by the

4 electrochemical pump system are mixed with each other before entering the separation
5 column.

1 27. The system of claim 1 wherein the electrochemical pump system and
2 the separation column are disposed on the separated substrate with a fluidic connection
3 between the electrochemical pump system and the separation column and are configured such
4 that the electrochemical pump system provides the elution for the separation process inside
5 the separation column.

1 28. The system of claim 1 further comprising a nozzle coupled to the
2 separation column through the outlet of the separation column, the nozzle being adapted to
3 output one or more separated components in a sequential order.

1 29. The system of claim 28 wherein the nozzle being coupled to transfer
2 the one or more separated components to a mass spectrometry process using an electrospray
3 ionization process.

1 30. The system of claim 1 further comprising a detection device coupled to
2 separation column through the outlet of the separation column.

1 31. The system of claim 30 wherein the detection device being disposed on
2 the same substrate with the separation column.

1 32. The system of claim 30 wherein the detection device is selected from a
2 group consisting of a UV analyzer, a conductivity analyzer, a refractive index analyzer, a
3 fluorescence analyzer, an electrochemical analyzer, a light scattering analyzer, and a mass
4 spectrometer.

1 33. The system of claim 1 wherein the electrochemical pump system and
2 the separation column are constructed from at least one selected from a group consisting of
3 multi-chip packaging, injection molding, photolithography, dry etching, wet etching,
4 evaporation, sputtering, and chemical vapor deposition.

1 34. A microfluidic system for electrospray ionization (ESI) and mass
2 spectrometry (MS), the system comprising:
3 a substrate;

an electrochemical pump system disposed on the substrate, the electrochemical pump system comprising a plurality of electrolysis pumps and having at least one outlet; each of the electrolysis pumps comprising:

- a chamber;
- a plurality of electrodes, the electrodes being coupled to an electrical source;
- a fluid inside the chamber, and the fluid being contacted with the electrodes; and
- an inlet and an outlet;

an electrospray ionization (ESI) nozzle disposed on the substrate, the ESI nozzle having an inlet, an outlet, a micro channel coupled between the inlet and the outlet, and an ESI electrode within the micro channel; the inlet of the ESI nozzle being coupled to the outlet of the electrochemical pump system;

a mass spectrometer, the mass spectrometer including an inlet, the inlet being coupled to the outlet of the ESI nozzle;

wherein the electrochemical pump system and the ESI nozzle are configured such that the electrochemical pump system provides a driving force to cause the fluid to flow through the micro channel of the ESI nozzle and flow out through the outlet of the ESI nozzle; and the fluid emitted from the outlet of the ESI nozzle is transferred to the mass spectrometer as a voltage source is applied between the ESI electrode and the mass spectrometer.

35. The system of claim 34 wherein the plurality of electrolysis pumps are configured in parallel.

36. The system of claim 34 wherein the plurality of electrolysis pumps are configured in serial.

37. The system of claim 34 wherein the plurality of electrolysis pumps are configured in parallel and serial.

38. The system of claim 34 wherein the electrical source is selected from a group consisting of a voltage source, a current source, and a voltage/current source.

- 1 39. The system of claim 34 wherein the electrolysis pump is adapted to
2 maintain a pressure on the fluid in the chamber while the electrodes are biased using the
3 electrical source.
- 1 40. The system of claim 39 wherein the pressure is less than 1000 psia.
- 1 41. The system of claim 39 wherein the pressure is less than 100 psia.
- 1 42. The system of claim 34 wherein the chamber comprises about 1 micro
2 liter of fluid.
- 1 43. The system of claim 34 wherein the chamber comprises greater than
2 about 1 micrometer of fluid.
- 1 44. The system of claim 34 wherein the chamber comprises less than about
2 1 micrometer of fluid.
- 1 45. The system of claim 34 wherein the electrochemical pump system is
2 characterized to provide a flow rate of about 1 nanoliter per minute to about 1 micro liter per
3 minute through the separation column.
- 1 46. The system of claim 34 wherein the electrochemical pump system is
2 characterized to provide a flow rate of less than about 1 nanoliter per minute through the
3 separation column.
- 1 47. The system of claim 34 wherein the electrochemical pump system is
2 characterized to provide a flow rate of greater than about 1 micro liter per minute through the
3 separation column.
- 1 48. The system of claim 34 wherein the chamber and the ESI nozzle are
2 made of materials including Parylene.
- 1 49. The system of claim 34 wherein the chamber and the ESI nozzle are
2 made of materials selected from a group consisting of SU-8, silicone, silicon, silicon oxide,
3 glass, Teflon, PEEK, and other polymer materials.

1 50. The system of claim 34 wherein the electrodes of the electrolysis
2 pumps and the ESI electrode are made of at least a material selected from a group consisting
3 of carbon, platinum, gold, aluminum, titanium, chromium, and other noble metals.

1 51. The system of claim 34 wherein the fluid being an electrolyte that is
2 selected from a group consisting of organic liquid, inorganic liquid, or a combination of
3 inorganic liquid and organic liquid.

1 52. The system of claim 51 wherein the organic liquid is selected from a
2 group consisting of acetonitrile, methanol, ethanol, tetrahydrofuran, isopropanol, and
3 toluene.

1 53. The system of claim 34 wherein the electrolysis pump further
2 comprising a plurality of chambers configured in series and containing same or different fluid
3 inside each chamber.

1 54. The system of claim 34 further comprising a mixer on the same
2 substrate coupled between the electrochemical pump system and the ESI nozzle, the mixer is
3 configured such that different fluids injected from the electrochemical pump system are
4 mixed with each other before entering the ESI nozzle.

1 55. The system of claim 34 wherein the electrochemical pump system and
2 the ESI nozzle are disposed on the separated substrate with a fluidic connection between the
3 electrochemical pump system and the ESI nozzle and are configured such that the
4 electrochemical pump system provides the driving force to push the fluid through the ESI
5 nozzle, and the fluid emitted from the outlet of the ESI nozzle is transferred to the mass
6 spectrometer as a voltage source is applied between the ESI electrode and the mass
7 spectrometer.

1 56. The system of claim 34 wherein the electrochemical pump system and
2 the ESI nozzle are constructed from at least one selected from a group consisting of multi-
3 chip packaging, injection molding, photolithography, dry etching, wet etching, evaporation,
4 sputtering, and chemical vapor deposition.

1 57. A method for transferring fluid on a microfluidic chip based on an
2 electrochemical actuation, the method comprising:

transferring a fluid into a chamber through an inlet within a substrate;
providing an electrical connection using a plurality of electrodes coupled to
the chamber;
transferring a portion of the fluid from the chamber through an outlet while
applying an electrical energy to the plurality of electrodes using the electrical connection,
whereupon the portion of the fluid is transferred free from any coupling to an external fluidic
source;
wherein the transferring a portion of the fluid is performed in response to the
electrical energy applied to the plurality of electrodes.

58. The method of claim 57 further comprising using the portion of the
fluid for a separation process.

59. The method of claim 57 further comprising transferring the portion of
the fluid through a nozzle.

60. The method of claim 57 further comprising sealing the fluid in the
chamber.

61. The method of claim 57 further comprising isolating the fluid in the
chamber.

62. The method of claim 57 wherein the transferring of the portion of the
fluid is provided only by applying the electrical energy to the microfluidic chip.

63. A method for controlling fluid through a microfluidic system in a
liquid chromatography application, the method comprising:
transferring fluid from an inlet into a chamber, the chamber being formed on a
first portion of a substrate, the chamber comprising a plurality of electrodes, the plurality of
electrodes being configured to apply electrical forces to the fluid;
applying an electrical source between the plurality of electrodes;
causing an electrochemical reaction within the chamber based upon the
application of the electrical source onto the electrodes, the electrodes being coupled to the
fluid; and
generating a gaseous species from the electrochemical reaction to increase a
pressure within the chamber;

12 coupling a separation column to the chamber;
13 using the pressure in the chamber to provide driving force for the elution in the
14 separation column for liquid chromatography; and
15 controlling the elution by adjusting the electrical source that applied the
16 plurality of electrodes.

1 64. The method of claim 63 wherein the electrical forces comprise an
2 electrical current.

1 65. The method of claim 63 wherein the electrical forces comprise a
2 voltage.

1 66. The method of claim 63 wherein the elution being isocratic.

1 67. The method of claim 63 wherein the elution being gradient.

1 68. The method of claim 63 wherein the pressure in the chamber also
2 provide driving force for a sample injection in the separation process.

1 69. The method of claim 63 further comprising capturing a signal
2 associated with a parameter of the fluid in the chamber; and using the captured signal to
3 adjust a level of the electrical source between the plurality of electrodes.

1 70. The method of claim 63 wherein the fluid in the chamber is a first fluid
2 and the separation column comprises a second fluid, the first fluid being different from the
3 second fluid, whereupon the second fluid being separated into one or more components as the
4 second fluid passes through the separation column.

1 71. The method of claim 63 further comprising transferring the one or
2 more components in a sequential manner from the separation column through a nozzle, the
3 nozzle being coupled to the separation column.

1 72. A method for controlling fluid through a microfluidic system in a
2 liquid chromatography application, the method comprising:
3 applying an electrical source between a plurality of electrodes to cause an
4 electrochemical reaction within a first fluid in a chamber coupled to the plurality of
5 electrodes;

6 generating a gaseous species from the electrochemical reaction in the first
7 fluid to increase a pressure within the chamber; and
8 transferring a second fluid through a separation column using the pressure
9 associated with the chamber for liquid chromatography.

1 73. The method of claim 72 wherein the first fluid is a working media for
2 the electrochemical reaction and the second fluid is a solvent for liquid chromatography.

1 74. The method of claim 72 further comprising transferring the one or
2 more components in a sequential manner from the separation column through a nozzle, the
3 nozzle being coupled to the separation column.

1 75. A method for performing liquid chromatography using a multi-
2 chamber arrangement, the method comprising:
3 applying an electrical source between a plurality of electrodes to cause an
4 electrochemical reaction within a first fluid in a first chamber, the first chamber being among
5 a plurality of chambers, each of the chambers being numbered from 1 through N, where N is
6 an integer greater than 1, the first fluid being from a plurality of fluids numbered from 1
7 through N, each of the fluids being respectively associated with each of the chambers;
8 generating a gaseous species from the electrochemical reaction in the first
9 fluid to increase a first pressure within the first chamber;
10 transferring a first liquid chromatography fluid from a first reservoir to a
11 separation column for liquid chromatography using the first pressure associated with the first
12 chamber, the first liquid chromatography fluid being from a plurality of liquid
13 chromatography fluids numbered from 1 through N, each of the liquid chromatography
14 fluids being associated with a respective reservoir also numbered from 1 through N; and
15 applying, generating, and transferring for any of the other chambers including
16 any of the other respective fluids and reservoirs.

1 76. The method of claim 75 wherein the first fluid is a working media for
2 the electrochemical reaction and the first liquid chromatography fluid is for liquid
3 chromatography.

1 77. The method of claim 75 wherein the applying, generating, and
2 transferring for the first chamber is performed simultaneously with steps of applying,
3 generating, and transferring for any of the other chambers.

1 78. The method of claim 75 wherein the applying, generating, and
2 transferring for the first chamber is performed sequentially with steps of applying, generating,
3 and transferring for any of the other chambers.

1 79. The method of claim 75 wherein each of the fluids numbered from 1
2 through N is a similar substance.

1 80. The method of claim 75 wherein each of the liquid chromatography
2 fluids numbered from 1 through N is a similar substance.

1 81. A method for controlling fluid through a microfluidic system for ESI-
2 MS, the method comprising:

3 transferring a first fluid from an inlet into a chamber, the chamber being
4 formed on a first portion of a substrate, the chamber comprising a plurality of electrodes, the
5 plurality of electrodes being configured to apply electrical forces to the first fluid;

6 applying an electrical source between the plurality of electrodes;
7 causing an electrochemical reaction within the chamber based upon the
8 application of the electrical source onto the electrodes, the electrodes being coupled to the
9 first fluid; and

10 generating a gaseous species from the electrochemical reaction to increase a
11 pressure within the chamber, the chamber being coupled to an ESI nozzle;

12 using the pressure in the chamber to provide a driving force to cause an
13 injection at a certain rate of a second fluid through the ESI nozzle for use in a mass
14 spectrometer;

15 controlling the rate of the injection by adjusting an electrical source coupled to
16 the plurality of electrodes.

1 82. The method of claim 81 wherein the electrical forces comprise an
2 electrical current.

1 83. The method of claim 81 wherein the electrical forces comprise a
2 voltage.

1 84. The method of claim 81 further comprising capturing a signal
2 associated with a parameter of the first fluid in the chamber; and using the captured signal to
3 adjust a level of the electrical source between the plurality of electrodes.

1 85. The method of claim 81 wherein the first fluid from the inlet into the
2 chamber is different from the second fluid through the ESI nozzle, whereupon the second
3 fluid being coupled to a MS through ESI process as the second fluid being injected from the
4 ESI nozzle and a voltage source being applied between the ESI nozzle and the MS.

1 86. The method of claim 81 wherein the first fluid from the inlet into the
2 chamber is the same as the second fluid through the ESI nozzle, whereupon the second fluid
3 being coupled to a MS through ESI process as the second fluid being injected from the ESI
4 nozzle and a voltage source being applied between the ESI nozzle and the MS.